2024 Volume 5, Issue 2
Satellite Oceanography and Meteorology
ISSN(Online): 2424-9505
ISSN(Print): 2424-8959

The Oceanographic-Meteorological Interactions in the Indian Ocean Monsoon Region as Observed by Satellite

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Abstract:

This paper aims to explore the interaction between oceanography and meteorology in the Indian Ocean monsoon region as observed by satellites. Through the analysis of satellite remote sensing data and related observational data in the Indian Ocean monsoon region, it elaborates on the influence of the monsoon on oceanographic elements such as ocean circulation, temperature, and salinity, as well as the feedback effect of the ocean on the monsoon climate, revealing the complex interaction mechanism between the two. This provides an important basis for further understanding the climate system and ocean environmental changes in the Indian Ocean region.

Keywords:

Indian Ocean Monsoon Region
Satellite Observation
Oceanography
Meteorology
Interaction Relationship

Online publication: December 27, 2024

1. Introduction

The Indian Ocean monsoon region is an important component of the global climate system. Its unique monsoon climate has a profound impact on the marine environment, and at the same time, changes in the ocean also have a reverse effect on the monsoon system. The development of satellite observation technology has provided us with a broad perspective and rich data, making the research on the oceanographic-meteorological interaction in the Indian Ocean monsoon region more comprehensive and in-depth. A thorough understanding of this interaction is of great significance for predicting climate change, changes in the marine ecological environment, and related natural disasters.

2. Overview of the Indian Ocean monsoon region

The Indian Ocean monsoon region mainly includes the northern Indian Ocean and its surrounding seas. The formation of the monsoon is closely related to the thermal differences between land and sea and the seasonal movement of pressure belts and wind belts. Under the significant influence of the monsoon, the southwest monsoon prevails from May to October, with strong southwest winds carrying a large amount of water vapor from the ocean to the land, with wind speeds reaching up to 12 m/s. The northeast monsoon prevails from October to April, with winds blowing from the Asian continent to the ocean. Spring (April) and autumn (November) are the transition periods of the monsoon, during which the sea surface wind field changes are complex. Under the combined effect of the monsoon and zonal winds, the upper ocean circulation in the eastern Indian Ocean shows significant seasonal variations. The characteristics of the eastern Indian Ocean circulation are not only affected by the monsoon transition but also coupled with interannual events such as the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) in the eastern Indian Ocean. Therefore, the upper ocean circulation in the eastern Indian Ocean is not completely synchronized with the monsoon transition [1]. This seasonal change in wind direction leads to significant changes in oceanographic elements such as ocean circulation, temperature, and salinity.

3. Application of satellite observation technology in Indian Ocean research

Satellite remote sensing technology, with its outstanding observation characteristics, has built a solid support system in the field of Indian Ocean monsoon region research. Its ultra-wide field of view can cover the vast Indian Ocean and capture a wealth of marine information; its short and efficient repeat observation cycle enables near real-time monitoring of dynamic marine meteorological elements, without missing any key details; and its excellent spatial and temporal resolution acts like a fine filter, accurately screening out subtle changes in oceanography and meteorology.

Specifically, ocean color satellites possess advanced detection capabilities, functioning as sharp “marine ecological detectives” that can capture the sea surface chlorophyll concentration, a key indicator with significant ecological value, with extremely high precision. This indicator serves as a precise “ecological microscope”, vividly reflecting the subtle changes in the marine ecological environment during its dynamic evolution, providing crucial clues for understanding marine primary productivity and the dynamics of plankton communities.

Ocean dynamic environment satellites, equipped with advanced precision detection instruments such as radar altimeters and microwave scatterometers, transform into “marine dynamic analyzers”, capable of high-precision quantification of core elements such as sea surface height and sea surface wind field. Relying on mature physical models and precise algorithms, they can deeply calculate the dynamic structure of ocean circulation and multiple parameters of ocean waves, comprehensively unlocking the internal operation logic of the marine dynamic system and revealing the complex laws of seawater movement [2]. Moreover, thermal infrared sensors, with their highly sensitive perception “antennae” for thermal radiation, effectively monitor the distribution pattern and continuous change trend of sea surface temperature in the spatiotemporal network, accurately capturing the dynamic changes in the marine thermal environment, providing first-hand data for understanding ocean heat transfer and sea-air interaction. In summary, the observational data sets collected and aggregated by different types of satellites are like a treasure trove of data rich in scientific resources, laying a solid foundation for in-depth exploration of the intricate and subtle interactions between oceanography and meteorology in the Indian Ocean monsoon region. These data are indispensable for subsequent research and provide a strong impetus for advancing research in this field.

4. The impact of monsoons on oceanographic elements

4.1. Impact on ocean currents

During the northeast monsoon period, the North Indian Ocean exhibits a typical and specific pattern of seawater flow, with the overall flow direction being southwestward. At this time, the northern branch of the South Equatorial Current converges with the northeast monsoon current flowing south along the African coast. Subsequently, the combined effect of these two currents causes the water flow to turn eastward, driving the formation of the equatorial countercurrent and establishing a counterclockwise circulation pattern in the North Indian Ocean [3].

In sharp contrast, when the southwest monsoon reaches its peak, the movement of seawater undergoes a significant reversal, with the flow direction roughly changing to eastward or northeastward. During this period, driven by the strong southwest monsoon, the northern branch of the South Equatorial Current crosses the equator and forcefully invades the North Indian Ocean, then advances northeastward along the Somali coast, eventually leading to the formation of the Somali cold current. This results in a clockwise circulation pattern in the North Indian Ocean. The seasonal dynamic changes in circulation induced by the periodic conversion of monsoons play a crucial role in the operation of the marine ecosystem, exerting a considerable influence on key aspects such as the transmission and distribution of heat within the ocean, the diffusion and migration of substances, and the distribution patterns, diffusion paths, and reproductive dynamics of biological populations. This deeply carves and shapes the distribution pattern of the marine ecological environment in both space and time, becoming one of the key driving forces maintaining the dynamic balance of the marine ecosystem.

4.2. Impact on sea surface temperature

The dynamic changes in the intensity of the monsoon system and the periodic conversion of wind direction directly and profoundly regulate the distribution pattern and variation trend of sea surface temperature in both space and time. During the period dominated by the northeast monsoon, air currents blow from the Asian continent towards the Indian Ocean, causing a significant loss of heat at the ocean surface and resulting in relatively low sea surface temperatures, especially in specific areas such as the Arabian Sea and the northern part of the Bay of Bengal.

In contrast, when the southwest monsoon becomes the dominant wind direction, warm and humid air currents rich in heat flow from the Indian Ocean towards the Asian continent. During this process, a large amount of heat continuously enters the ocean surface, causing a significant increase in sea surface temperature. High-precision sea surface temperature monitoring data obtained through satellite remote sensing technology clearly show that in January, when the northeast monsoon prevails, the average sea surface temperature in the northern Indian Ocean is approximately 24 ℃. As the seasons change and the southwest monsoon prevails in July, the average sea surface temperature in this region can rise to around 28 ℃ [4]. Moreover, the influence of monsoons is not limited to the direct regulation of sea surface temperature but also induces a series of secondary marine dynamic phenomena, among which upwelling is particularly prominent. For example, in the coastal area of Somalia, driven by the southwest monsoon, seawater undergoes intense vertical upward movement, with deep cold water rising to the ocean surface, causing a sharp drop in sea surface temperature in this area and creating a significant temperature gradient difference with the surrounding sea areas, which in turn has a profound impact on the structure and function of the regional marine ecosystem.

4.3. Impact on seawater salinity

The regulation of seawater salinity by the monsoon system is mainly achieved through the key processes of precipitation and evaporation. During the period dominated by the northeast monsoon, the Indian Ocean region is influenced by its climatic characteristics, resulting in relatively scarce precipitation and a significant increase in evaporation. This imbalance in water and heat budget leads to continuous concentration of seawater salinity, thereby maintaining a relatively high level of salinity. Particularly in the Arabian Sea and other areas, due to their unique geographical location and climatic conditions, the salinity of seawater can rise above 36‰ during the northeast monsoon period [5]. In stark contrast, when the southwest monsoon prevails, a large amount of moisture from the warm and humid surface of the Indian Ocean is carried to the land, bringing abundant precipitation to the oceanic regions. The injection of a large amount of fresh water dilutes the seawater, directly leading to a decrease in salinity. According to detailed analysis of data obtained from comprehensive satellite observations and on-site field observations, during the southwest monsoon period, under the influence of precipitation as the dominant factor, the salinity of seawater in the Arabian Sea and other areas can drop to around 34%.

In addition, the dynamic changes in the ocean circulation system also play a crucial role in shaping the distribution pattern of seawater salinity. Ocean currents with significant seasonal characteristics, such as the Equatorial Countercurrent and the Somali Current, with their unique seawater transport capabilities, drive the migration of seawater with different salinities across vast ocean areas. The Equatorial Countercurrent transports relatively low-salinity seawater from low latitudes to high latitudes along its flow path, while the Somali Current promotes the mixing and exchange of high-salinity and low-salinity seawater in specific areas, thereby causing complex changes in salinity in different sea areas and exerting a profound influence on the overall distribution pattern of seawater salinity in the Indian Ocean [6].

5. Feedback effects of the ocean on monsoon climate

5.1. Impact of sea surface temperature anomalies on monsoon intensity and timing

The abnormal fluctuations in sea surface temperature in the Indian Ocean play a key role in the dynamic changes of the monsoon system, exerting a crucial regulatory effect on the intensity and timing of monsoon onset. Specifically, when sea surface temperature shows an abnormally high trend, the heat exchange process between the ocean and the atmosphere is significantly enhanced, and the ocean, as a heat source, increases the heat flux to the atmosphere. This change in the thermodynamic process directly drives the intensification of the monsoon circulation system, strengthening the monsoon wind force, and to a certain extent, may lead to an earlier onset of the monsoon [7].

Conversely, if the sea surface temperature in the Indian Ocean is abnormally low, the heat transfer from the ocean to the atmosphere will weaken accordingly, thereby weakening the dynamic basis of the monsoon circulation and reducing the monsoon intensity. At the same time, the onset time of the monsoon is also likely to be delayed. Numerous research results show that during specific El Niño events, the sea surface temperature in the Indian Ocean often shows an abnormal warming phenomenon. This temperature anomaly triggers a chain reaction, significantly enhancing the intensity of the southwest monsoon and leading to a significant increase in precipitation in regions such as India. In contrast, during La Niña events, the sea surface temperature in the Indian Ocean is relatively low, which weakens the monsoon circulation and ultimately results in a decrease in precipitation in related regions.

5.2. Impact of ocean circulation on monsoon

The dynamic evolution of the ocean circulation system is not solely driven by the monsoon in a unidirectional manner; in fact, there exists a close two-way feedback mechanism between them. For instance, the abnormal variations in typical ocean currents such as the Equatorial Countercurrent and the Somali Current can significantly disrupt the distribution pattern of heat and water vapor at the ocean surface, and this change further penetrates into the formation basis and development process of the monsoon system. Specifically, when the equatorial countercurrent shows an enhanced trend, it carries the warm water mass near the equator to advance forcefully towards higher latitudes. This process is like laying a “hot blanket” at the bottom of the atmosphere, causing changes in the thermal structure of the atmosphere. As the key medium for the formation and development of monsoons, the reshaping of the thermal structure of the atmosphere directly affects the intensity and path of the monsoon.

High-precision data obtained through satellite observations clearly show that in some specific years, once the intensity of the equatorial countercurrent undergoes non-periodic fluctuations or its path deviates from the conventional trajectory, the Indian Ocean monsoon system will respond rapidly. Its wind direction will change accordingly, and its intensity will adaptively adjust, thereby causing significant disturbances to the climate patterns of surrounding regions and triggering a series of chain reactions such as abnormal precipitation distribution and intensified temperature fluctuations, profoundly affecting the stability and development of regional ecosystems.

6. Conclusion

There exists a close and intricate interaction between oceanography and meteorology in the Indian Ocean monsoon region. The periodic changes of the monsoon significantly regulate key oceanographic parameters such as ocean circulation, temperature distribution, and salinity.

Conversely, changes in the ocean state, such as abnormal fluctuations in sea surface temperature and adjustments in ocean circulation, also exert feedback effects on the monsoon climate. Thanks to the rapid development of satellite observation technology, we can obtain a large amount of valuable data to deeply explore this interaction process. At the same time, the continuous optimization of numerical simulation technology provides us with powerful means to understand and predict this complex interaction. Looking to the future, with the continuous improvement of satellite observation technology and the maturation of numerical simulation methods, our understanding of the interaction between oceanography and meteorology in the Indian Ocean monsoon region will become more thorough, which will provide a more solid scientific basis for addressing climate change challenges and maintaining the marine ecological environment.

Disclosure statement

The author declares no conflict of interest.

References

[1] Liang H, 2021, Research on Three-Dimensional Hydrological Characteristics During the Monsoon Transition Period in the Tropical Eastern Indian Ocean, thesis, Guangdong Ocean University.

[2] Hu Y, Zhang Z, Jian M, et al., 2020, Variability of the East Asian Summer Meridional Water Vapor Transport and Its Impact on Extreme Precipitation. Journal of Tropical Meteorology, 36(6): 784–794.

[3] Chen H, 2020, Characteristics of Summer Water Vapor Transport Over the Tropical Indian Ocean and Its Impact on Precipitation in the South Asian Monsoon Region. Journal of Nanjing University of Information Science and Technology (Natural Science Edition), 12(4): 442–449.

[4] Zhang J, Sun W, Ma Y, et al., 2020, Analysis of the Spatiotemporal Characteristics of the Temperature Front in the Monsoon Belt of the Eastern Indian Ocean From 2000 to 2017. Journal of Applied Oceanography, 39(1): 100–108.

[5] Li J, Mao J, 2019, Impact of 30–60 Day Intraseasonal Oscillation of the Asian Summer Monsoon on Persistent Extreme Precipitation in Eastern China. Chinese Journal of Atmospheric Sciences, 43(4): 796–812.

[6] Zhao S, Pu X, 2019, In-Depth Teaching Exploration of the Monsoon Circulation in the Core of the Indian Ocean Under the Perspective of Core Literacy. Middle School Geography Teaching Reference, 2019(6): 51–53.

[7] Wang T, Chen J, Yan J, et al., 2022, Spatiotemporal Distribution of Information Entropy of Precipitation Isotopes in China and Its Tracing of Water Vapor Transport. Advances in Water Science, 33(4): 581–591.